Euphytica **136:** 201–210, 2004.

Andean beans (*Phaseolus vulgaris* L.) with resistance to the angular leaf spot pathogen (*Phaeoisariopsis griseola*) in southern and eastern Africa

Vas D. Aggarwal[1], Marcial A. Pastor-Corrales[2,*], Rowland M. Chirwa[3] & Robin A. Buruchara[4]
[1]*Ex-CIAT Breeder and Consultant, 21 Burnhope Drive, Brampton, ON, Canada L6X3R5;* [2]*Research Plant Pathologist, USDA-ARS, Vegetable Laboratory, Bldg. 010A, Rm. 240, 10300 Baltimore Av., Beltsville, MD 20705-2350, U.S.A.;* [3]*CIAT Bean Breeder and Regional Coordinator, P.O. Box 158, Lilongwe, Malawi;* [4]*Plant Pathologist, CIAT, Kawanda Agriculture Research Institute, P.O. Box 6247, Kampala, Uganda; (*author for correspondence; e-mail: pastorm@ba.ars.usda.gov)*

Received 7 October 2003; accepted 28 February 2004

Key words: angular leaf spot, CAL 143, common bean, disease resistance, *Phaeoisariopsis griseola*, *Phaseolus vulgaris*

Summary

Common beans (*Phaseolus vulgaris*) are separated into two distinct groups: Andean and Middle American. We identified CAL 143 as the first Andean bean with resistance to angular leaf spot disease caused by *Phaeoisariopsis griseola*. Angular leaf spot is the most widespread and economically important bean disease in southern and eastern Africa, and it is especially severe on the extensively grown Andean beans. Cal 143 was resistant in Malawi, South Africa, Tanzania, and Zambia, but it was susceptible in Uganda. This was attributed to the presence of races of *P. griseola* in Uganda not present in the other countries. We identified two additional Andean bean lines, AND 277 and AND 279, with resistance to angular leaf spot in Malawi. We also characterized the virulence diversity of 15 isolates of *P. griseola* from southern and eastern Africa into nine different races. Five of six isolates from Malawi and two of seven from Uganda, obtained from large-seeded Andean beans, were characterized into four different races considered Andean. These were compatible only or mostly with large-seeded Andean cultivars. The other eight isolates from Uganda, Malawi, and the Democratic Republic of Congo, obtained from a small- or medium-seeded Middle American beans, were characterized into five different Middle American races. These were compatible with Middle American and Andean cultivars. CAL 143 was resistant or intermediate under greenhouse conditions to all but one of the same 15 isolates from southern and eastern Africa, but it was susceptible to an isolate from Uganda obtained from a medium-seeded Middle American bean.

Introduction

Common bean (*Phaseolus vulgaris* L.) cultivars are separated into two distinct groups known as the Andean and the Middle American gene pools (Gepts, 1988). Several morphological, biochemical, molecular, and other attributes differentiate these gene pools. The large-seeded (>40 g 100-seed weight^{-1}) Andean beans originated in the Andean mountains of South America, while the small-seeded (<25 g 100-seed weight^{-1}) and medium-seeded (25–40 g 100-seed weight^{-1}) Middle American beans originated in Mexico and Central America (Singh, 2001).

Common bean production and consumption ranks very high in the countries of southern and eastern Africa (Wortmann et al., 1999). In this region, where large-seeded Andean beans are extensively grown, the common bean is fundamentally a small-scale farmers' crop grown with few purchased inputs and exposed to a myriad of biological, edaphic, and climatic constraints (Wortmann et al., 1998). Among the various diseases that attack the common bean, angular leaf spot

(ALS), caused by the fungus *Phaeoisariopsis griseola* (Sacc.), Ferraris is very widespread and damaging in tropical and subtropical bean producing countries (Allen et al., 1989; Liebenberg & Pretorius, 1997). ALS is rated as the second most significant among 29 biotic and abiotic constraints that afflict the bean crop in Africa and as the most important and widespread of the biotic constraints. ALS is particularly destructive to Andean beans that are extensively grown and consumed in Malawi and other southern and eastern African countries. Control of ALS can be enhanced by the use of clean seed, free of the ALS pathogen, variety mixtures, cultural practices, and fungicides (Correa-Victoria et al., 1989; Pyndji & Trumann, 1992). However, the most practical, economically feasible, and effective control for a small-scale farmer in Africa comes from the use of resistant varieties. Although sources of ALS resistance have been identified in common bean (Busogoro et al., 1999; Mahuku et al., 2003, Pastor-Corrales et al., 1998; Schwartz et al., 1982), these sources have not been evaluated under field conditions in Africa, and it has not been ascertained whether the identified sources included beans of the Andean gene pool.

There are many races (virulence phenotypes) of *P. griseola* (Mahuku et al., 2000; Nietsche et al., 2001). These races frequently vary in time and space; thus, a bean variety that is resistant in one year or location may be susceptible in another. Although Andean and Middle American beans are grown in southern and eastern Africa, Andean beans are preferred for their large seed size, ease to cook, and taste; but Andean beans are very susceptible to ALS in these countries, particularly in Malawi. On the other hand, Middle American beans have been reported as resistant to ALS in the Democratic Republic of Congo and Malawi (Musuku et al., 1990; Pyndji & Trumann, 1992). An effort to identify the sources of ALS resistance was made in the early to mid-90s by the Bean Program of the Centro Internacional de Agricultura Tropical (CIAT) in Malawi. A large number of germplasm lines introduced from the Bean Program at CIAT Headquarters in Cali, Colombia, were evaluated under field conditions in Malawi and other countries in southern and eastern Africa with the following objectives: (1) identify Andean cultivars with resistance to ALS, (2) explore the virulence diversity of *P. griseola*, and (3) evaluate under greenhouse conditions the reaction of Andean beans with resistance to ALS in eastern and southern Africa to newly characterized races of *P. griseola* from this region. In this paper we synthesize the findings from a breeding project aiming at improving beans for disease resistance and report the results obtained from these studies.

Materials and methods

Identification and confirmation of ALS resistance in CAL 143 in Malawi

Common bean germplasm and improved lines were evaluated for their reaction to the ALS pathogen under natural field conditions and disease infestation levels. More than 2000 bean accessions received from CIAT Headquarters in Cali, Colombia, were screened during the crop season of 1992–1993 at the experimental fields of Bunda College of Agriculture, located in central Malawi near the capital city of Lilongwe (latitude 13° 58′S, altitude 1,100 m above mean sea level [masl]). The group of beans tested consisted of both Andean and Middle American types, including CAL 143, a large-seeded Andean bean belonging to the Calima grain type. Calima is a popular Andean bean variety from Colombia with large, red mottle seeds. The abbreviation CAL was used at CIAT to name Andean bean breeding lines similar to Calima. CAL 143 has a determinate growth habit and a seed weight of about 42 g 100-seed weight^{-1}. All bean cultivars were evaluated in a non-replicated nursery that included the most popular local check variety, Nasaka, as a control. Disease scores were recorded using the CIAT's visual scale of 1–9, where a reading of between 1 and 3 was considered resistant, 4 and 6 intermediate, and 7 and 9 susceptible (van Schoonhoven & Pastor-Corrales, 1987). Confirmation of ALS resistance in CAL 143 and other common bean cultivars in Malawi was done under field conditions at Bembeke, a site also situated in central Malawi but at a higher altitude than Bunda College. Bembeke is located at 14° 20′S 34° 30′E, 1,600 masl with an annual mean rainfall of 1000 mm distributed in a mono-modal rainfall, where rains start around December and finish about 4 months later. Annual mean minimum and maximum air temperatures are 9 °C and 22 °C, respectively. Year-to-year infestation and severity of the disease was more reliable at Bembeke than at the Bunda College site, thus making it a better site for identifying bean genotypes with resistance to ALS. To confirm the ALS resistance in CAL 143, disease data from the Preliminary Bean Yield Trial (PBYT) and the Southern African Regional Bean Yield Trial (SARBYT) planted at Bembeke in the 1993–94, 1994–95, and 1995–96 crop seasons was used. Both of these trials

had CAL 143 along with other bean varieties belonging to the Middle American and Andean gene pools. No artificial inoculations were made, thus any disease that developed was due to natural infestations only. Disease scores were recorded using the CIAT's visual scale of 1–9. The numbers of varieties included in each of the two trials during the 3 years of testing were as follows: PBYT = 34 (1993–94), 36 (1994–95), 31 (1995–96), and each year the trial had three replications, consisting of a 2-row plot, 4-m long; SARBYT = 15 (1993–94), 15 (1994–95), 18 (1995–96), and each year the trial had four replications, consisting of a 4-row plot, 4-m long.

Reaction of CAL 143 to ALS under field conditions in other southern African countries

CAL 143 was also evaluated under field conditions in other countries in southern and eastern Africa. It was tested as part of the SARBYT Regional Variety Trial described earlier. The testing was conducted in Tanzania, South Africa, and Zambia in southern Africa and Uganda in eastern Africa. The reaction of CAL 143 to the ALS pathogen in these countries was also recorded, using the standard evaluation system based on a visual score of 1–9.

Additional sources of ALS resistance in Andean beans

An additional 147 Andean and Middle American germplasm entries from the VEF breeding nursery received from CIAT, were evaluated at the Bembeke research station during the 1996–97 and 1997–98 crop seasons. In 1996–97, this nursery was first planted in a non-replicated trial, but in the following year (1997–98), it was replicated twice. Again the screening was carried out under field conditions similar to those in previous years, based on natural infestations of the disease. The data on selected new lines that showed resistance to ALS were compared to CAL 143 and the local check variety, Nasaka, both of Andean type.

Virulence analysis of African isolates of Phaeoisaripsis griseola

The isolates of *P. griseola* used in this study were collected from naturally infected leaves and pods of common bean grown under field conditions in Malawi, Uganda, Rwanda, and the Democratic Republic of Congo. During the collection of the disease samples, data were recorded on the name of the bean cultivar, seed size, growth habit, and collection site. Isolation, purification, production of monosporic isolates, storage of *P. griseola*, and inoculum preparation and concentration for each monosporic isolate, in this study, were conducted as described by Pastor-Corrales et al. (1998). Races of the pathogen were identified inoculating a set of 12 common bean differential cultivars under greenhouse conditions at the CIAT headquarters in Cali, Colombia. Six of these differential cultivars were large-seeded and of Andean origin and six were small- or medium-seeded Middle American beans. Monosporic cultures of each isolate at a concentration of 2×10^4 conidia ml^{-1} were inoculated on each differential, following the methodology described by Pastor-Corrales et al. (1998).

Reaction of Andean beans to individual isolates of the ALS pathogen from Africa

Andean bean cultivars DRK 57, SUG 92, SUG 118, and AFR 150, evaluated as resistant to ALS in various field locations in Africa and CAL 143, were inoculated under greenhouse conditions at the CIAT headquarters in Cali, Colombia, with 15 African isolates of *P. griseola*: six from Malawi, seven from Uganda, and one each from Rwanda and the Democratic Republic of Congo. These lines had commercial bean color liked in Malawi and other countries in southern Africa. Nine plants of each bean line were sown in three pots, three plants per pot, and inoculated with a spore suspension 1×10^4 spores ml^{-1}, following the previously described methodology for evaluation of bean germplasm (Pastor-Corrales et al., 1998).

Results

Identification and confirmation of ALS resistance in CAL 143 in Malawi

CAL 143 was found to be free of ALS during the crop season of 1992–93 at Bunda, Malawi. Subsequently, CAL 143 was evaluated during the following three seasons at Bembeke, Malawi. The level of ALS infestation at Bembeke was high and uniform on the susceptible bean genotypes, but CAL 143 exhibited a resistant reaction during all these 3 years (Table 1). These results confirmed, with a high degree of certainty, the resistance to ALS observed in CAL 143 in the 1992–93 crop season at Bunda. This finding was the first ever confirmed report of ALS

Table 1. Reaction of CAL 143 and other common bean cultivars to *Phaeoisariopsis griseola*, the pathogen of the angular leaf spot (ALS) disease, under field conditions at Bembeke, Malawi, 1993–1996

	ALS disease score and reaction type[a]					
Bean cultivar	1993–1994	Reaction	1994–1995	Reaction	1995–1996	Reaction
1. Preliminary Bean Yield Trial (PBYT)						
Andean						
CAL 143	3	R	4	I	3	R
Nasaka	8	S	4	I	–	–
CAL 113	5	I	6	I	6	I
Middle American						
A 286	2	R	–	–	–	–
EMP 308	–	–	–	–	3	–
Mean	6	I	6	I	5	I
±SE	0.7		0.52		–	
Significance	***		**		–	
2. Southern African Regional Bean Yield Trial (SARBYT)						
Andean						
CAL 143	2	R	2	R	3	R
Nasaka	7	S	–	–	–	–
Phalombe/Local	6	I	9	S	7	S
Middle American						
BAT 477	2	R	–	–	–	–
Nandi	–	–	4	I	4	I
Mean	4	I	5	I	6	I
±SE	0.4		0.5		–	
Significance	***		**		–	

[a]ALS disease evaluations using a 1 to 9 rating scale, where 1 = *no visible symptoms of the disease* and 9 = *very severe symptoms* (Schoonhoven & Pastor-Corrales, 1987). ALS reaction type: 1–3 = resistant (R); 4–6 = intermediate (I); 7–9 = susceptible (S).

resistance in an Andean bean in Malawi, and therefore, was considered a major research accomplishment of the Malawi bean program. Because of its high yield potential (up to 2000 kg/ha) and exhibited resistant reaction to several diseases under field conditions, CAL 143 was released in Malawi as Napilira in 1995 (Chirwa et al., 1997). In addition to ALS resistance, CAL 143 also showed intermediate levels of resistance to powdery mildew (caused by *Erysiphe polygoni*), halo blight (caused by *Pseudomonas syringae* pv. *phaseolicola*) and tolerance to soil-fertility stresses in Malawi (Malawi Bean Improvement Program Annual Report, 1993–94). CAL 143 was also resistant to rust (caused by *Uromyces appendiculatus*) in South Africa, as observed by Pastor-Corrales and Steadman during the Bean Rust Workshop field trip in the KwaZulu-Natal province of South Africa in March 2002.

Reaction of CAL 143 to ALS under field conditions in other southern African countries

Results obtained from South Africa, Tanzania, and Zambia showed that CAL143 had a resistant or intermediate reaction to isolates of the ALS pathogen prevalent in these countries but a susceptible reaction at Kawanda, Uganda, and eastern Africa (Table 2). In a personal communication, Meri Liebenberg (2003) confirmed that CAL 143 was resistant to ALS under field conditions in South Africa (Liebenberg, personal communication).

Additional sources of ALS resistance in Andean beans

Two additional Andean bean lines, AND 277 and AND 279, were identified as resistant to ALS in the 1996–97 crop season in Malawi. Resistance in them was

Table 2. Reaction of CAL 143 and other common bean cultivars to *Phaeoisariopsis griseola*, the pathogen of the angular leaf spot disease (ALS), in southern and eastern Africa, 1993–1994

	ALS disease score and reaction type[a]							
	Southern Africa				Eastern Africa			
	Potchefstroom, South Africa[b]		Uyole, Tanzania		Misamfu, Zambia		Kwanda, Uganda[c]	
Bean cultivar	Score	Reaction	Score	Reaction	Score	Reaction	Score	Reaction
CAL 143	<3	R	3	R	4	I	8	S
Nasaka	–	–	7	S	5	I	–	–
Local	>7	S (Kranskop)[d]	6	I	5	I	8 (G5686)[e]	S
Mean	–	–	4	–	5	–	–	–
±SE	–	–	0.3	–	0.5	–	–	–

[a]ALS disease evaluations using a 1 to 9 rating scale, where 1 = *no visible symptoms of the disease* and 9 = *very severe symptoms* (Schoonhoven & Pastor-Corrales, 1987). ALS Reaction type: 1–3 = resistant (R); 4–6 = intermediate (I); 7–9 = susceptible (S).
[b]Source: M Liebenberg, ARC, Potchefstroom, South Africa, personal communication.
[c]Source: CIAT Bean Program Annual Report, 1995.
[d]Locally released ALS susceptible bean variety in South Africa.
[e]Large-seeded Andean bean accession from CIAT.

confirmed in the 1997–98 crop season (Table 3). The Pedigrees of these lines are as follows: CAL 143 = G 12229 × AND 277; AND 277 = G 21720 × BAT 1386; AND 279 = G 21720 × BAT 1386; and BAT 1386 = G 6616 × (G 4523 × (G 4523 × G 76)). These pedigrees showed that AND 277 and AND 279 were sister lines; i.e., they originated from the same cross, and AND 277 was one of the parents of CAL 143.

Virulence analysis of African isolates of Phaeoisaripsis griseola

The virulence phenotype (race) of six isolates of *P. griseola* from Malawi, seven from Uganda, and one each from Rwanda and the Democratic Republic of Congo, was characterized by inoculating separately each of these isolates on an international set of

Table 3. Additional Andean sources of resistance to *Phaeoisariopsis griseola*, the angular leaf spot pathogen (ALS) of beans, identified at Bembeke in Malawi during 1996–1997 and 1997–1998[a]

	ALS score (1–9 Scale)[b]					
	1996–1997				1997–1998	
Variety	Score 1	Reaction	Score 2	Reaction	Score	Reaction
Andean						
AND 277	1	R	5	I	3	R
AND 279	2	R	3	R	2	R
Middle American						
MAR 3	2	R	2	R	3	R
Control						
CAL 143	2	R	3	I	4	I
NASAKA	–	–	9	S	9	S
Mean (147 lines)	4	I	8		7	S
SE±	–		–		0.7	
Significance	–		–		**	

[a]Identified in the VEF, a breeding nursery from the International Center for tropical Agriculture (CIAT).
[b]ALS disease evaluations were made using a 1 to 9 rating scale, where 1 = *no visible symptoms of the ALS disease* and 9 = *very severe symptoms*. 1–3 = resistant (R); 4–6 = intermediate (I); 7–9 = susceptible (S).

Table 4. Identification and virulence phenotype of 15 *Phaeoisariopsis griseola* (PG) isolates from three common bean (*Phaseolus vulgaris*) producing countries in Africa

		Bean differential cultivars[b] and their binary number value[c]												
		Andean						Middle American						virulence
PG isolate ID[a]	Origin seed size	A 1	B 2	C 4	D 8	E 16	F 32	G 1	H 2	I 4	J 8	K 16	L 32	phenotype (race)
PG4MWI	L		b	C	D	e								30-0
PG5MWI	L		b	C	D	e								30-0
PG2MWI	L	a	b	C	D	e								31-0
PG3MWI	L	a	b	C	D	e								31-0
PG6MWI	L		b	C	D	e		g		i				30-5
PG3UGD	L	a	b	C	D	e	f	g	h	i				63-7
PG4UGD	L	a	b	C	D	e	f	g	h	i				63-7
PG2UGD	M	a	b	C	D	e	f	g		i		k		63-21
PG1UGD	S	a	b	C	D			g	h	i			L	15-39
PG1MWI	S	a	b	C	D	e		g	h	i			L	31-39
PG5UGD	M	a	b	C	D	e		g	h	i			L	31-39
PG6UGD	S	a	b	C	D	e		g	h	i			L	31-39
PG7UGD	S	a	b	C	D	e		g	h	i			L	31-39
PG1RUA		a	b	C	D	e	f	g	h	i			L	63-39
PG1ZAR		a	b	C				g	h	i		k	L	7-55

[a]Country of origin of isolate: MLW = Malawi, UGD = Uganda, RUA = Rwanda, ZAR = Democratic Republic of Congo (Formerly Zaire).

[b]Andean differential cultivars: A = Don Timoteo, B = G11796, C = Bolón Bayo, D = Montcalm, E = Amendoin, F = G5686; Middle American differential Cultivars: G = PAN 72, H = G 2858, I = Flor de Mayo, J = Mexico 54, K = BAT 332, L = Cornell 49242. Lower case letters a to i indicate a compatible host pathogen interaction.

[c]Binary values for the differential cultivars are: A and G = 1, B and H = 2, C and I = 4, D and J = 8, E and K = 16, and F and L = 32. The sum of the values of the susceptible cultivars will give the binary number of that specific race. A hyphen is used to separate the sum of the Andean and Middle American cultivars; e.g., Race 30-5 = virulent on Andean cultivars B, C, D, and E and on Middle American Cultivars G and I.

differential cultivars (Table 4). Based on the reaction of the bean differential cultivars to each of the 15 isolates characterized, considerable variation was observed in the virulence exhibited by these isolates. Five of the six isolates from Malawi were collected from large-seeded Andean beans and were similar to each other (Table 4). Two of these isolates were characterized as race 30-0, two as race 31-0, and one as race 30-5. Races 30-0 and 31-0 were very similar to each other in their virulence phenotype; both were compatible only with Andean differential cultivars but differed in their reaction to Andean cultivar Don Timoteo. Race 30-1 was compatible with Don Timoteo, whereas race 30-0 was not. The other isolate from Malawi, characterized as race 30-5, was compatible with most of the Andean cultivars and with two of the Middle American differential cultivars. All of these three races (30-0, 30-1, and 30-5) were considered Andean because they were obtained from large-seeded Andean beans and were compatible only or mostly with large-seeded Andean differential cultivars. The only isolate from Malawi obtained from a small-seeded bean cultivar (most likely a bean belonging to the Middle American gene pool) was characterized as race 31-39. This race was compatible with five Andean and four Middle American differential cultivars. Races compatible with most of the Middle American and some Andean bean cultivars have been considered Middle American. In general, the results obtained with the six Malawian isolates, albeit in small number, suggested that most Andean beans in Malawi harbor Andean races of the ALS pathogen that characteristically were compatible only or mostly with Andean bean cultivars.

The isolates from Uganda were also segregated into two different groups of races, one Andean and the other Middle American (Table 4). Two of the Ugandan

Table 5. Reaction to five common bean lines to 15 different isolates of *Phaeoisariopsis griseola* from Africa inoculated under greenhouse conditions

Isolate			Reaction of common bean lines[a]				
ID	Origin seed size	Race	DRK 57	SUG 92	SUG 118	AFR 530	CAL 143
PG4MWI	L	30-0	S^9	S^8	R^1	R^1	R^1
PG5MWI	L	30-0	S^9	I^4	R^1	R^1	R^1
PG2MWI	L	31-0	S^9	I^5	R^1	R^1	R^1
PG3MWI	L	31-0	S^9	S^9	R^1	R^1	R^1
PG6MWI	L	30-5	S^9	I^5	R^1	R^1	R^1
PG3UGD	L	63-7	S^7	R^2	S^7	R^3	R^3
PG4UGD	L	63-7	S^8	I^4	S^9	I^5	I^4
PG2UGD	M	63-21	S^9	S^9	S^9	I^6	S^9
PG1UGD	S	15-39	S^7	S^7	S^8	I^6	R^2
PG1MWI	S	31-39	S^9	S^8	S^9	S^9	R^2
PG5UDG	M	31-39	S^8	S^7	S^9	S^8	R^2
PG6UGD	S	31-39	S^7	S^7	S^7	S^7	R^3
PG7UGD	S	31-39	S^7	S^8	S^8	S^7	R^3
PG1RUA	–	63-39	S^9	S^7	S^7	I^6	I^4
PG1ZAR	–	7-55	S^9	R^2	S^7	I^6	R^3

[a]The number above the letter corresponds to the severity of reaction under greenhouse conditions in 1995. ALS disease evaluations were made using a 1 to 9 rating scale, where 1 = *No visible symptoms of the ALS disease* and 9 = *very severe symptoms* (Schoonhoven and Pastor-Corrales, 1987). Reaction type: 1–3 = resistant (R); 4–6 = intermediate (I); 7–9 = susceptible (S).

isolates were obtained from large-seeded beans and were characterized as the Andean race 63-7. This race was compatible with all Andean differential cultivars and with some of the Middle American differential cultivars. This race was fairly similar to the Andean race 30-5 from Malawi. A Ugandan isolate obtained from medium-seeded beans and characterized as race 63-21, was compatible with Andean and Middle American differential cultivars. This race was considered Middle American. The remaining four isolates from Uganda were also characterized as Middle American races. Three of these isolates, obtained from small- or medium-seeded beans, were characterized as race 31-39. The fourth isolate, also obtained from small-seeded beans, was characterized as race 15-39. The last two isolates, one each obtained from Rwanda and the Democratic Republic of Congo, were characterized as Middle American races 63-39 and 7-55, respectively. All the Middle American races found in the course of this study were compatible with some Middle American differential cultivars that were resistant to all Andean races. In summary, 15 different isolates of the ALS pathogen were characterized into 10 different races. Six isolates from Malawi were characterized into four different races, three Andean (30-0, 31-0, and 30-50) and one Middle American (31-39); seven isolates from Uganda into four races, three Middle American (63-21, 15-39, and 31-39) and one Andean (63-7); and one isolate each from Rwanda and the Democratic Republic of Congo into two Middle American races (63-39 and 7-55), respectively.

Reaction of Andean beans to various individual isolates of the ALS pathogen from Africa

The isolates of *P. griseola* from Malawi, Uganda, Rwanda, and the Democratic Republic of Congo were used to evaluate the reaction of CAL 143 and other four Andean bean lines under greenhouse conditions at CIAT headquarters (Table 5). CAL 143 had a resistant reaction to all isolates from Malawi, and a resistant or intermediate reaction to all but one isolate from Uganda. The only isolate that produced a susceptible reaction on CAL 143 was classified as the Middle American race 63-21, found only in Uganda. The resistant reaction of CAL 143 under greenhouse conditions to all isolates from Malawi coincided with the reaction observed for this cultivar under field conditions in that country. It was also noteworthy that CAL 143 was found susceptible to only one isolate of

P. griseola from Uganda, corroborating the observation that CAL 143 was susceptible under field conditions in Uganda. Additionally, in a personal communication, Liebenberg from South Africa (2003) reported that CAL 143 was resistant under greenhouse conditions to most (90%) of the isolates of ALS pathogen from South Africa, and susceptible to only a few isolates that she characterized as Middle American (Liebenberg, personal communication). She noted that CAL 143 was resistant under field conditions in South Africa. The other four Andean cultivars included in the study were susceptible to the majority of the 15 isolates (Table 5), indicating that CAL 143 possessed a much wider level of resistance compared to other bean varieties.

Discussion

In this study, we identified CAL 143 as the first Andean common bean with resistance to the angular leaf spot disease under field conditions in Malawi and other countries in eastern and southern Africa. This is a region where common beans are a primary staple food legume, a major source of dietary protein, iron, fiber, complex carbohydrates, and an essential component of the nutrition to millions of men, women, and children. CAL 143 was resistant in Malawi during one crop season at Bunda and three seasons at Bembeke. It was also resistant in Potchefstroom, South Africa; Uyole, Tanzania; and Misamfu, Zambia. This discovery was particularly important because ALS is the most widespread and damaging disease of beans in Africa and because Andean beans, which are extensively grown in Malawi and other southern and eastern African countries, are very susceptible to ALS. Cultivars with disease resistance offer small-scale bean farmers a practical and economic way of managing ALS and other diseases. For the small-scale farmer of Africa, other disease-management alternatives, such as fungicides and clean seed, often are not economical or practical and are difficult to implement.

Although CAL 143 showed a remarkable level of resistance to ALS in several countries in southern and eastern Africa, it was susceptible in Uganda. This was attributed to the presence of race 63-21 of the ALS pathogen found in Uganda but not in Malawi. This observation underlines the fact that different races of the ALS pathogen exist in different parts of the African continent and different sources of resistance will be required to manage ALS with genetic resistance. Concerted efforts are needed to find new sources of resistance and to broaden the genetic base of beans in African countries.

In the beginning, resistance to ALS in the Andean beans in Malawi and other southern and eastern African countries was limited to only the Andean bean cultivar, CAL 143. Later, two additional ALS resistant Andean bean lines, AND 277 and AND 279, were identified. These two lines had resistance to ALS in Malawi during the 1996–1997 and 1997–1998 crop seasons. Finding two new Andean ALS resistant beans quickly raised the question of whether they represented new sources of resistance or were somehow related to CAL 143. The pedigrees of these lines, presented in the Results section, showed that AND 277 and AND 279 were sister lines, AND 277 was one of the parents of CAL 143, and that these lines probably had a common donor parent that contributed the resistance to ALS. Further clarifications will be sought to pinpoint the donor parent for resistance to ALS in these cultivars. However, if confirmed that one common parent contributed the ALS resistance in CAL 143 and in AND 277 and AND 279, it is also possible that the same gene for resistance to ALS present in CAL 143 is also present in many or most Andean bean genotypes. If so, such condition would not be unique to ALS resistance in beans. The *Co-1* gene that provides resistance to anthracnose (caused by *Colletotrichum lindemuthianum*) is also the only anthracnose resistance gene so far found in the Andean gene pool (Alzate-Marin et al., 2003). This gene is present in majority of Andean beans with allelic differences ($Co\text{-}1^2$ to $Co\text{-}1^5$) existing between the cultivars. An allele of *Co-1*, named $Co\text{-}1^5$, for resistance to anthracnose is present in AND 277 (Alzate-Marin et al., 2003). Additionally, AND 277 is also one of the few Andean cultivars with resistance to several isolates of *P. griseola* from Brazil (Sartorato, 2002). It appears then, that CAL 143 and AND 277 could be utilized as sources of resistance to several diseases in bean improvement programs.

Studies have also revealed that the race diversity of the ALS pathogen can be separated into two distinct groups, one Andean and another Middle American (Guzman et al., 1995; Mahuku et al., 2003; Pastor-Corrales, 1996). Andean races are usually compatible only or mostly with the Andean beans while the Middle American races are compatible with Middle American and Andean beans, but are generally more virulent on the former. It has been posited that the Andean and Middle American races of *P. griseola* have evolved separately with the Andean and Middle American common bean gene pools, respectively (Guzman et al.,

1995). During the course of this study, the virulence diversity of 15 isolates of *P. griseola* from southern and eastern Africa were characterized into nine different races. Six isolates were from Malawi, seven from Uganda, and one each from Rwanda and the Democratic Republic of Congo. It was significant that five of the six isolates from Malawi, obtained from large-seeded Andean beans, when characterized by inoculating them on a set of six Andean and six Middle American bean differential cultivars, were differentiated into three different races: 30-0, 31-0, and 30-5 that were similar to each other and were compatible only or mostly with large-seeded Andean differential cultivars. On the basis of their virulence phenotype, i.e., compatibility with only or mostly Andean beans, these were considered Andean races of the ALS pathogen. The only isolate from Malawi obtained from a small-seeded Middle American bean was characterized as race 31-39. This fitted the description of a Middle American race of the pathogen that typically was compatible with both Middle American and Andean differential cultivars (Mahuku et al., 2002; Pastor-Corrales, 1996). The preponderance of Andean races of the ALS pathogen in Malawi was not surprising, considering that most beans grown in Malawi are of Andean origin, and Andean races of *P. griseola* are usually associated with the Andean beans. On the other hand, the diversity among races of the ALS pathogen in Uganda was quite different from those of Malawi. Five of the seven isolates from Uganda were obtained from small- or medium-seeded Middle American beans. These, characterized as Middle American races 63-21, 15-39, and 31-39, were very similar to each other in their virulence to the differential cultivars; they were compatible with both Andean and Middle American differential beans. Ugandan race 31-39 was also found in Malawi, indicating some overlap of races between these two countries. The other two races from Uganda (15-39 and 63-21) were also similar to the race 31-39 found in Malawi and Uganda. The other two Ugandan isolates obtained from large-seeded Andean beans were both characterized as the Andean race 63-7 that was compatible mostly with Andean differential cultivars. Some Andean races of the ALS pathogen from Africa (races 30-5 and 63-7), all obtained from large-seeded beans, were compatible with some of the Middle American bean differential cultivars. However, these races were not compatible with any of the Middle American cultivars BAT 332 and Cornell 49242 that are often susceptible to Middle American races of the ALS pathogen (Mahuku et al., 2002; Pastor-Corrales et al., 1998). Although only 15 isolates of the ALS pathogen from southern Africa were characterized in this study, these results suggest that the virulence diversity of *P. griseola* in Africa is similar to that found in Latin America (Mahuku et al., 2002; Pastor-Corrales, 1996). These results also suggest that it is likely that a similar evolution had occurred between the Latin American and African isolates of the ALS pathogen with their common bean host.

Based on the resistant reaction of CAL 143 to the ALS disease under field conditions in different countries in southern and eastern Africa, it was not entirely surprising that CAL 143 was also resistant under controlled greenhouse conditions to all but one of the 15 isolates of *P. griseola* from Africa. CAL 143 was resistant to all isolates from Malawi, Rwanda, and the Democratic Republic of Congo, resistant or intermediate to most isolates from Uganda, and susceptible to only one isolate from Uganda, obtained from a medium-seeded Middle American bean. Finally, it is important to point out that the results obtained during the course of these studies clearly indicate that CAL 143 is a unique Andean bean with commercial grain color, high yield, and with resistance to ALS and other diseases in southern and eastern Africa.

Acknowledgements

We are most grateful to Carlos Jara, Guillermo Castellanos, and Juan Cuasquer for their technical assistance.

References

Allen, D.J., M. Dessert, P. Trutmann & J. Voss, 1989. Common beans in Africa and their constraints. In: H.F. Schwartz & M.A. Pastor-Corrales (Eds.), Bean Production Problems in the Tropics, 2nd edn., pp. 9–33. CIAT, Cali, Colombia.

Alzate-Marin, A.L., K.M. Arruda, E.G. de Barros & M.A. Moreira, 2003. Allelism studies for anthracnose resistance genes of common cultivar AND 277. Annu Rep Bean Improv Coop 46: 173–174.

Busogoro, J.P., M.H. Jijakly & P. Lepoivre, 1999. Identification of novel sources of resistance to angular leaf spot to angular leaf spot disease of common bean. Plant Breeding 118: 417–423.

Chirwa, R.M., V.D. Aggarwal & A.D. Mbvundula, 1997. New bean varieties released in Malawi. Annu Rep Bean Improv Coop 40:143–144.

Correa-Victoria, F.J., M.A. Pastor-Corrales & A.W. Saettler, 1989. Angular Leaf Spot. In: H.F. Schwartz & M.A. Pastor-Corrales, (Eds.), Bean Production Problems in the Tropics, 2nd edn., pp. 59–76. CIAT, Cali, Colombia.

Gepts, P., 1988. A Middle American and Andean common bean gene pool. In: P. Gepts (Ed.), Genetic Resources of *Phaseolus* Beans, pp. 375–390. Kluwer, Dordrecht, The Netherlands.

Guzman, P., R.L. Gilbertson, R.L., Nodari, W.C. Johnson, S.R. Temple, D. Mandala, A.B.C. Mkandawire & P. Gepts, 1995. Characterization of variability in the fungus *Phaeoisariopsis griseola* suggests coevolution with the common bean (*Phaseolus vulgaris*). Phytopathology 85: 600–607.

Liebenberg, M.M. & Z.A. Pretorius, 1997. A review of angular leaf spot of common bean (*Phaseolus vulgaris* L.). Afr Plant Prot 3: 81–106.

Mahuku, G.S., M.A. Henriquez, J. Munoz & R.A. Buruchara, 2002. Molecular markers dispute the existence of the Afro-Andean group of the angular leaf spot pathogen, *Phaeoisariopsis griseola*. Phytopathology 92(6): 580–589.

Mahuku, G.S., C. Jara, C. Cajiao & S. Beebe, 2003. Sources of resistance to angular leaf spot (*Phaeoisariopsis griseola*) in common bean core collection, wild *Phaseolus vulgaris* and secondary gene pool. Euphytica 130: 302–313.

Malawi Bean Improvement Program. Annual Reports: 1993–94, 1994–95 and 1995–96.

Musuku, W.A.B., W.W. Saka, J.C. Mbalule & S. Kamwanba, 1990. Evaluation of bean (*Phaseolus vulgaris*) germplasm against angular leaf spot and some root rot nematode (*Meloidogyne*) species in Malawi. Zimbabwe J Agric Res 28: 15–21.

Nietsche, S., A. Borém, G.A. de Carvalhos, T.J. de Paula Júnior, C. Fortes Ferreira, E. Gonçalves de Barros & M. Alves Moreira, 2001. Genetic Diversity of *Phaeoisariopsis griseola* in the state of Minas Gerais, Brazil. Euphytica 117: 77–84.

Pastor-Corrales, M.A., 1996. Traditional and molecular confirmation of the coevolution of beans and pathogens in Latin America. Ann Rep Bean Improv Coop 39: 46–47.

Pastor-Corrales, M.A., C. Jara & S.P. Singh, 1998. Pathogenic variation, source of, and breeding for resistance to *Phaeoisariopsis griseola* causing angular leaf spot in common bean. Euphytica 103: 161–171.

Pyndji, M.M. & P. Trutmann, 1992. Managing angular leaf spot on common bean in Africa by supplementing farmer mixtures with resistant varieties. Plant Dis 76: 1144–1147.

Sartorato, A., 2002. Common bean genotypes resistant to angular leaf spot. Ann Rep Bean Improv Coop 45: 144–145.

Schwartz, H.F., M.A. Pastor-Corrales & S.P. Singh, 1982. New sources of resistance to anthracnose and angular leaf spot of beans (*Phaseolus vulgaris* L.). Euphytica 31: 741–754.

Singh, S.P., 2001. Broadening the genetic base of common bean cultivars: A review. Crop Sci 41: 16–591675.

van Schoonhoven, A. & M.A. Pastor-Corrales, 1987. Standard System for the Evaluation of Bean Germplasm. CIAT, Cali, Colombia.

Wortmann, C.S., A. Eledu & S. David, 1999. Bean as a cash crop in sub-Saharan Africa. Annu Rep Bean Improv Coop 42: 103–104.

Wortmann, C.S., R.A. Kirkby, C.A. Eledu & D.J. Allen, 1998. Atlas of Common Bean (*Phaseolus vulgaris* L.) Production in Africa. CIAT, Cali, Colombia.